

1 1. A method of positioning a movable body suspended in a magnetic bearing
2 system comprising a displacement sensor, comprising:

3 measuring the axial position of the movable body with the sensor to produce a
4 displacement output;

5 adjusting the displacement output to account for a sensor offset;

6 converting the adjusted displacement output to a force for positioning the movable
7 body; and

8 and positioning the movable body with said force.

9
10 2. The method of claim 1, wherein converting the adjusted displacement output
11 to a force comprises inputting the adjusted displacement output into a position controller
12 configured to determine the point of substantial axial equilibrium of the movable body.

13
14 3. The method of claim 2, wherein converting the adjusted displacement output
15 to a force for positioning the movable body comprises creating a mechanical force to position
16 the movable body at the point of substantial axial equilibrium.

17
18 4. The method of claim 2, wherein converting the adjusted displacement output
19 to a force for positioning the movable body comprises creating an electromagnetic force to
20 position the movable body at the point of substantial axial equilibrium.

21
22 5. The method of claim 1, wherein adjusting the displacement output to account
23 for the sensor offset comprises estimating the sensor offset and adjusting the displacement
24 output by the estimated sensor offset.

25
26 6. The method of claim 5, wherein estimating the sensor offset further comprises
storing a plurality of displacement outputs over a period of time.

1 7. The method of claim 6, wherein the period of time is determined by
2 comparing a variance of the plurality of displacement output against a predetermined
3 threshold to determine a start time and an end time.
4

5 8. The method of claim 6, wherein a selective plurality of displacement outputs
6 are used to estimate the sensor offset, the displacement offsets being selected by comparing
7 a magnitude of the displacement offset against a predetermined threshold.

8 9. The method of claim 6, wherein estimating the sensor offset further comprises
9 taking an average value of the stored displacement outputs.
10

11 10. The method of claim 6, wherein estimating the sensor offset further comprises
12 taking an weighted average value of the stored displacement outputs.
13

14 11. The method of claim 6, wherein estimating the sensor offset further comprises
15 determining a median value of the stored displacement outputs.
16

17 12. The method of claim 6, wherein estimating the sensor offset further comprises
18 determining the mode value of the stored displacement outputs.
19

20 13. The method of claim 5, wherein the magnetic bearing system further
21 comprises memory for storing displacement outputs.
22

23 14. The method of claim 13, further comprising storing the estimated sensor
24 offset in memory.
25

26 15. The method of claim 13, further comprising storing adjusted displacement
outputs in memory.

1 16. The method of claim 14, further comprising recalling the estimated sensor
2 offset and utilizing the estimated sensor offset to position the movable body to a point of
3 substantial axial equilibrium.
4

5 17. The method of claim 15, further comprising recalling the adjusted
6 displacement output and utilizing the adjusted displacement output to position the movable
7 body to a point of substantial axial equilibrium.
8

9 18. The method of claim 1, wherein measuring comprises measuring the axial
10 position of the movable body when it is levitating.
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26

1 19. A method of positioning a movable body suspended in a magnetic bearing
2 system comprising a displacement sensor, comprising:

3 measuring the displacement of the movable body with the sensor to produce an
4 displacement output;

5 estimating a sensor offset using the displacement output;

6 adjusting the displacement output by the estimated sensor offset to create an adjusted
7 displacement output;

8 inputting the adjusted displacement output into a body position controller configured
9 to determine the point of substantial axial equilibrium of the movable body;

10 converting the adjusted displacement output to an electromagnetic force for
11 positioning the movable body;

12 positioning the movable body to a point of substantial axial equilibrium; and

13 repeating the previous steps.

14 20. The method of claim 19, wherein estimating the sensor offset further
15 comprises storing a plurality of displacement outputs over a period of time, the plurality of
16 displacement outputs being derived from axial position measurements of the movable body.

17 21. The method of claim 20, wherein the period of time is determined by
18 comparing a variance of the plurality of displacement output against a predetermined
19 threshold to determine a start time and an end time.

20 22. The method of claim 20, wherein a selective plurality of displacement outputs
21 are used to estimate the sensor offset, the displacement offsets being selected by comparing
22 a magnitude of the displacement offset against a predetermined threshold.

1 23. The method of claim 20, wherein estimating the sensor offset further
2 comprises taking an average value of the stored displacement outputs.
3
4 24. The method of claim 20, wherein estimating the sensor offset further
5 comprises taking an weighted average value of the stored displacement outputs.
6
7 25. The method of claim 20, wherin estimating the sensor offset further
8 comprises determining a median value of the stored displacement outputs.
9
10 26. The method of claim 20, wherein estimating the sensor offset further
11 comprises determining the mode value of the stored displacement outputs.
12
13 27. The method of claim 19, wherein the magnetic bearing system further
14 comprises memory for storing data.
15
16 28. The method of claim 27, further comprising storing the estimated sensor
17 offset in memory.
18
19 29. The method of claim 28, further comprising recalling the estimated sensor
20 offset and utilizing said offset to position the movable body to a point of substantial axial
21 equilibrium during a reset of the system.
22
23 30. The method of claim 20, further comprising storing the adjusted displacement
24 outputs in memory.
25
26 31. The method of claim 30, further comprising recalling the adjusted
displacement output and utilizing the adjusted displacement output to position the movable
body to a point of substantial axial equilibrium.
27
28 32. The method of claim 19, wherein measuring comprises measuring the
movable body when it is levitating.

1 33. A system for positioning a movable body suspended in a magnetic bearing
2 apparatus, the system comprising:

3 a sensor for measuring the displacement of the movable body and providing a
4 displacement output;

5 a sensor offset compensation module, configured to receive said displacement output
6 from the sensor and adjust said displacement output to account for a sensor offset;

7 a position control module configured to receive and use the adjusted displacement
8 output of the sensor offset compensation module to approximate the point of substantial axial
9 equilibrium of the movable body; and

10 an actuator module for converting an output of the position control module into a
11 force for positioning the movable body to the point of substantial axial equilibrium.

12 34. The system of claim 33, wherein the sensor is configured to convert the
13 displacement output to a displacement voltage.

14 35. The system of claim 33, wherein the sensor offset compensation module is
15 configured to provide an estimated sensor offset and adjust the displacement output by the
16 estimated sensor offset to create an adjusted displacement output.

17 36. The system of claim 35, wherein the sensor offset compensation module is
18 configured to store a plurality of displacement outputs over a period of time, the plurality of
19 displacement outputs being derived from axial position measurements of the positioned
20 movable body.

1 37. The system of claim 36, wherein the sensor offset compensation module
2 compares a variance of the plurality of displacement outputs against a predetermined
3 threshold to determine a start time and an end time.
4

5 38. The system of claim 36, wherein a selective plurality of displacement outputs
6 are used to estimate the sensor offset, the displacement offsets being selected by comparing
7 a magnitude of the displacement offset against a predetermined threshold.
8

9 39. The system of claim 36, wherein the sensor offset compensation module
10 estimates the sensor offset by taking an average value of the stored displacement outputs.
11

12 40. The system of claim 36, wherein the sensor offset compensation module
13 estimates the sensor offset by taking a weighted average value of the stored displacement
outputs.
14

15 41. The system of claim 36, wherein the sensor offset compensation module
estimates the sensor offset by determining a median value of the stored displacement outputs.
16

17 42. The system of claim 36, wherein the sensor offset compensation module
18 estimates the sensor offset by determining the mode value of the stored displacement outputs.
19

20 43. The system of claim 33, wherein the actuator module is configured to convert
the output from the position control module to create a mechanical force to position the
21 movable body to the point of substantial axial equilibrium.
22

23 44. The system of claim 33, wherein the actuator module is configured to convert
the output from the position control module to create an electromagnetic force to position the
24 movable body to the point of substantial axial equilibrium.
25

1 45. The system or method of claim 33, wherein the magnetic bearing system
2 further comprises memory for storing data.

3 46. The system of claim 45, wherein the memory stores an estimated sensor offset
4 in memory.

5 47. The system of claim 46, wherein the position control module uses the
6 estimated sensor offset stored in memory to position the movable body to a point of
7 substantial axial equilibrium during a reset of the system.

8 48. The system of claim 45, wherein the memory stores an adjusted displacement
9 output in memory.

10 49. The system of claim 46, wherein the position control module uses the adjusted
11 displacement output stored in memory to position the movable body to a point of substantial
12 axial equilibrium during a reset of the system.

1 50. A method of positioning a magnetically suspended rotor in a pump apparatus,
2 the pump apparatus comprising at least one permanent magnet, at least one electro magnet,
3 a rotor position sensor, and a rotor position controller, comprising:
4

5 measuring the displacement of the rotor in the axial direction with the sensor to
6 produce a displacement output;

7 converting the displacement output into a displacement voltage;

8 estimating a sensor offset using the displacement output;

9 adjusting the displacement output by the estimated sensor offset to create an adjusted
10 displacement output;

11 inputting the adjusted displacement output into the rotor position controller
12 configured to determine the point of substantial axial equilibrium of the rotor;

13 converting the output of the rotor position controller into an electromagnetic force;

14 positioning the rotor to a point of substantial axial equilibrium by adjusting the
15 voltage to the electromagnet; and
16

17 repeating the previous steps.

18 51. The method of claim 50, further comprising storing the estimated sensor
19 offset in memory.

20 52. The method of claim 51, further comprising recalling the estimated sensor
21 offset and utilizing said offset to position the movable body to a point of substantial axial
22 equilibrium during a reset of the system.

23 53. The method of claim 50, further comprising storing the adjusted displacement
24 output in memory.

1 54. The method of claim 53, further comprising recalling the adjusted
2 displacement output and utilizing said offset to position the movable body to a point of
3 substantial axial equilibrium during a reset of the system.
4

5 55. The method of claim 50, wherein estimating the sensor offset further
6 comprises averaging a plurality of stored displacement outputs, said plurality of displacement
7 outputs being derived by measuring the displacement of the positioned rotor over a period
8 of time.
9

10 56. The method of claim 55, wherein the sensor offset compensation module
11 compares a variance of the plurality of displacement outputs against a predetermined
12 threshold to determine a start time and an end time.
13

14 57. The method of claim 56, wherein the sensor offset compensation module
15 estimates the sensor offset by taking an average value of the displacement outputs stored
16 between the start time and the end time.
17

18 58. The method of claim 50, wherein a selective plurality of displacement outputs
19 are used to estimate the sensor offset, the displacement offsets being selected by comparing
20 a magnitude of the displacement offset against a predetermined threshold.
21

22 59. The method of claim 58, wherein estimating the sensor offset further
23 comprises taking an average value of the stored displacement outputs.
24

25 60. The method of claim 1, wherein measuring comprises measuring the axial
26 position of the movable body when it is levitating.
27

1 61. A magnetically suspended pump apparatus, comprising:
2 a housing comprising an inlet port and an outlet port for receiving and discharging
3 fluid respectively;
4 a rotor positioned within the housing for pumping blood between the housing's inlet
5 port and outlet port;
6 a plurality of permanent magnets for passively controlling the radial position of the
7 rotor radially, and the pitch and yaw of the rotor;
8 an electromagnet for actively controlling the position of the rotor in the axial
9 direction;
10 an electromagnetic motor for rotating the rotor about a central axis;
11 a sensor for measuring the axial displacement of the rotor;
12 an offset compensation module for adjusting an output of the sensor to account for
13 sensor offset;
14 a rotor position controller for positioning the rotor at the point of substantial axial
15 equilibrium; and
16 an actuator for creating an electromagnetic force to position the rotor.
17
18 62. The pump apparatus of claim 61, further comprising a computer comprising
19 memory for storing and recalling sensor data.
20
21 63. The pump apparatus of claim 62, wherein the computer controls the operation
22 of the pump apparatus.
23
24 64. The pump apparatus of claim 62, wherein the computer is configured to recall
25 saved sensor data upon reboot or reset of the computer.

MADSON & METCALF, P.C.

ATTORNEYS AT LAW
900 GATEWAY TOWER WEST
15 WEST SOUTH TEMPLE
SALT LAKE CITY, UTAH 84101

1 65. The pump apparatus of claim 61, wherein the position controller is configured
2 to balance the passively controlled forces acting on the rotor.
3

4 66. The pump apparatus of claim 61, wherein the rotor position controller is a
5 virtual zero power controller.
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26

1

2

3 67. A method of positioning a magnetically suspended rotor in a pump apparatus,
4 the pump apparatus comprising at least one permanent magnet, at least one electro magnet,
5 a rotor position sensor, and a rotor position controller, comprising:

6

7 measuring the displacement of the rotor in a plurality of positions to produce a
8 plurality of displacement output;

9

10 estimating a sensor offset using the displacement outputs;
11 adjusting the displacement output by the estimated sensor offset to create an adjusted
12 displacement output;

13

14 inputting the adjusted displacement output into the rotor position controller
15 configured to determine the point of substantial axial equilibrium of the rotor; and

16

17 converting the output of the rotor position controller into a force for positioning the
18 rotor.

19

20

21

22

23

24

25

26